(2) The mould, with base-plate attached, shall be weighed to the nearest 1 g (W_1). The mould shall be placed on a solid base, e.g. a concrete floor or plinth, and the moist soil shall be compacted into the mould, with the extension attached, in three layers of approximately equal weight, each layer being given 25 blows from the rammer dropped from a height of 12 in (30·5 cm) above the soil. The blows shall be uniformly distributed over the surface of each layer. The operator shall ensure that the tube of the rammer is kept clear of soil so that the rammer always falls freely.

The amount of soil used shall be sufficient to fill the mould, leaving not more than about ¼ in (6 mm) to be struck off when the extension is removed (see Note 5). The extension shall be removed and the compacted soil shall be carefully levelled off to the top of the mould by means of the straightedge. The mould and soil shall then be weighed to the nearest 1 g (W_2).

(3) The compacted soil specimen shall be removed from the mould and placed on the large metal tray. A representative sample of the specimen shall be taken and its moisture content (m) shall be determined as in Test 1(A), 1(B) or 1(C).

(4) The remainder of the soil specimen shall be broken up, rubbed through the ¾ in (20 mm) BS test sieve, and then mixed with the remainder of the original sample. Suitable increments of water (see Note 6) shall be successively added and mixed into the sample, and the above procedure from operations (2) to (4) shall be repeated for each increment of water added. The total number of determinations made shall be at least five, and the range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

4.1.3.2 ***Soil susceptible to crushing during compaction*** (see Note 1)

(1) Five or more 2½ kg samples of air-dried soil passing the ¾ in (20 mm) BS test sieve, obtained as described in 1.4 shall be taken (see Note 2). The samples shall each be thoroughly mixed with different amounts of water to give a suitable range of moisture contents (see Notes 3 and 4). The range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range (see Note 6).

(2) Each sample shall be treated as in 4.1.3.1(2) above.

(3) Each compacted specimen shall be treated as in 4.1.3.1(3) above.

(4) The remainder of each soil specimen shall be discarded.

4.1.4 Calculations*

(1) The weight of wet compacted soil per cubic foot (bulk density (γ)) of each compacted specimen shall be calculated from the formula (see Note 7):

$$\gamma = \frac{W_2 - W_1}{15 \cdot 12} \text{ (lb/ft}^3\text{)}$$

* See Form M, Appendix B.

where W_1 = weight of mould and base (g)
W_2 = weight of mould, base and soil (g)

(2) The weight of dry soil per cubic foot (dry density (γ_d)) shall be calculated from the formula:

$$\gamma_d = \frac{100\gamma}{100 + m} \text{ (lb/ft}^3\text{)}$$

where m = moisture content of soil (per cent).

(3) The dry densities (γ_d) obtained in a series of determinations shall be plotted against the corresponding moisture contents (m). A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve shall be determined, and the zero, 5% and 10% air voids lines plotted for comparison (see 1.1).

4.1.5 Reporting of results

4.1.5.1 The following values shall be reported:

(1) The dry density in lb/ft³ corresponding to the maximum point on the moisture content/dry density curve shall be reported as the 'maximum dry density' to the nearest whole number.

(2) The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the 'optimum moisture content' and quoted to the nearest 0·2 for values below 5%, to the nearest 0·5 for values from 5% to 10%, and to the nearest whole number for values exceeding 10% (see Note 8).

(3) The amount of stone retained on the ¾ in (20 mm) BS test sieve* shall be reported to the nearest 1%.

4.1.5.2 The method of obtaining the result shall be stated, i.e. BS 5·5 lb (2·5 kg) rammer method. The procedure used shall also be stated, i.e. single sample or separate samples.

NOTES ON TEST 11

NOTE 1. The soil should be considered susceptible to crushing during compaction if the sample contains granular material of a soft nature, e.g. soft limestone, sandstone, etc., which is reduced in size by the action of the 5·5 lb (2·5 kg) rammer. The procedure given in 4.1.3.2 for soils susceptible to crushing during compaction can be applied to all soils if it is convenient to do so.

NOTE 2. The removal of small amounts of stone (up to 5%) retained on a ¾ in (20 mm) BS test sieve will affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density. The exclusion of a large proportion of stone coarser than ¾ in (20 mm) (such as is present for example in a gravel of 3 in (76 mm) maximum size) may have a major effect on the density obtained compared

* BS 410, 'Test sieves'.

with that obtainable with the soil as a whole, and on the optimum moisture content. There is at present no generally accepted method of testing or of calculation for dealing with this difficulty in comparing laboratory compaction test results with densities obtained in the field. The following notes may be of assistance in providing a basis for action which will avoid major errors, they are not considered comprehensive, however, and are not to be read as part of the standard method of test. (The term gravel should be taken to include rock fragments.)

(1) For soils containing up to about 20% or 25% of coarse gravel or cobbles, a correction may be calculated for the maximum dry density based on the displacement of a proportion of soil of given density by stone of known specific gravity. A check of the validity of this calculation may be obtained by replacing the coarse gravel in the soil by an equal quantity of ¾–⅜ in (20–10 mm) gravel of similar characteristics and carrying out a compaction test on this material. For soils containing little fine or medium gravel the proportion of coarse gravel permissible may be extended to 50% or 40%.

(2) For soils containing larger proportions of coarse gravel, or cobbles, various methods have been advocated, but it is not considered that any can be satisfactory which does not involve the use of a mould which is large compared with the maximum size of gravel or cobbles involved. It is common to carry out the compaction tests on such soils in a 6 in (15 cm) diameter mould of the same depth (4·584 in) (11·6 cm) as the standard mould. When this is done the number of blows per layer should be increased from 25 to 56 to allow for the increased area. California Bearing Ratio (CBR) moulds are sometimes used for this purpose but because of the difference in height (5 in) (13 cm) the number of blows per layer should be increased to 61.

NOTE 3. The amount of water to be mixed with air-dried soil at the commencement of the test will vary with the type of soil under test. In general, with sandy and gravelly soils a moisture content of 4% to 6% would be suitable, while with cohesive soils a moisture content about 8% to 10% below the plastic limit of the soil (PL-10 to PL-8) would usually be suitable.

NOTE 4. It is important that the water shall be thoroughly and adequately mixed with the soil, since inadequate mixing gives rise to variable test results. This is particularly important with cohesive soils when adding a substantial quantity of water to the air-dried soil. With clays of high plasticity, or where hand mixing is employed, it may be difficult to distribute the water uniformly through the air-dried soil by mixing alone, and it may be necessary to store the mixed sample in a sealed container for a minimum period of about 16 hours before continuing with the test.

NOTE 5. It is necessary to control the total volume of soil compacted, since it has been found that if the amount of soil struck off after removing the extension is too great, the test results will be inaccurate.

NOTE 6. The water added for each stage of the test should be such that a range of moisture contents is obtained which includes the optimum moisture content. In general, increments of 1–2% are suitable for sandy and gravelly soils and of 2–4% for cohesive soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum moisture content.

NOTE 7. The constant 15·12 only applies when the dimensions of the mould are as given in 4.1.2(1).

NOTE 8. For some highly permeable soils such as clean gravels, uniformly graded and coarse clean sands the results of the laboratory compaction test (5·5 lb (2·5 kg) rammer method) may provide only a poor guide for specifications on field compaction. The laboratory test often indicates higher values of optimum moisture content than would be desirable for field compaction and the maximum dry density is often much lower than the state of compaction that can readily be obtained in the field.

4.2 TEST 12. DETERMINATION OF THE DRY DENSITY/MOISTURE CONTENT RELATION—10 lb (4·5 kg) RAMMER METHOD

4.2.1 Scope. This test covers the determination of the weights of dry soil per cubic foot when the soil is compacted in a specified manner over a range of moisture contents including that giving the maximum weight of dry soil per cubic foot. In this test the compactive effort is greater than in Test 11, the weight of rammer being increased to 10 lb (4·5 kg) and the height of fall to 18 in (45·8 cm).

4.2.2 Apparatus

(1) A cylindrical metal mould, having an internal diameter of 4 in (10·2 cm) an internal effective height of 4·584 in (11·6 cm) and a volume of 1/30 ft³ (944 cm³). The mould shall be fitted with a detachable baseplate and a removable extension approximately 2 in (5·1 cm) high. One suitable design of mould is shown in Fig. 21.

(2) A metal rammer having a 2 in (5·1 cm) diameter circular face, and weighing 10 lb (4·5 kg). The rammer shall be equipped with a suitable arrangement for controlling the drop to the specified amount of 18 in (45·8 cm) (one suitable form of hand apparatus is shown in Fig. 23). A mechanical form of the apparatus may be used provided the essential dimensions of the rammer and mould are adhered to and provided that the rammer has a free vertical fall of the correct controlled height. It is also essential that the design of the machine is such that the mould rests on a heavy solid base.

(3) A balance readable and accurate to 1 g.

(4) A palette knife (a convenient size is one having a blade approximately 4 in (10 cm) long and ¾ in (2 cm) wide).

(5) A straightedge, e.g. a steel strip 12 in (30 cm) long, 1 in (2·5 cm) wide and ⅛ in (3 mm) thick, with one bevelled edge.

(6) A ¾ in (20 mm) BS test sieve* and a receiver.

(7) A large metal tray (a convenient size is one about 24 in (61 cm) × 18 in (46 cm) × 3 in (7·5 cm)).

(8) Apparatus for moisture content determination as described in Test 1(A), 1(B) or 1(C).

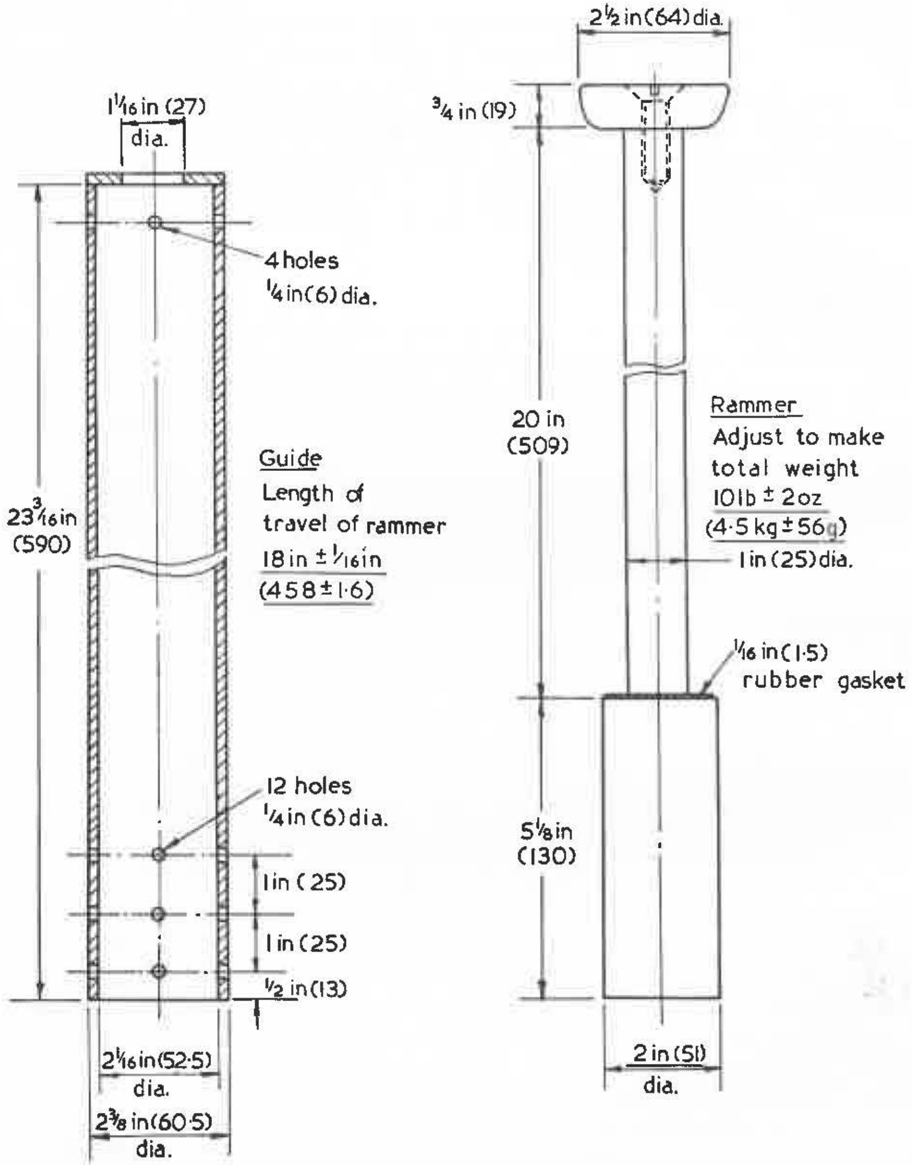
(9) Apparatus for extracting specimens from the mould (optional).

4.2.3 Procedure

4.2.3.1 ***Soil not susceptible to crushing during compaction*** (see Note 1)

(1) A 5 kg sample of air-dried soil passing the ¾ in (20 mm) BS test sieve obtained as described in 1.4 shall be taken (see Note 2). The sample shall be mixed thoroughly with a suitable amount of water depending on the soil type (see Notes 3 and 4).

* BS 410, ' Test sieves '.



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions underlined.)
Millimetre dimensions in brackets.

Fig. 23. 10 lb (4·5 kg) rammer for the compaction test

(2) The mould, with base-plate attached, shall be weighed to the nearest 1 g (W_1). The mould shall be placed on a solid base, e.g. a concrete floor or plinth, and the moist soil shall be compacted into the mould, with the extension attached, in five layers of approximately equal weight, each layer being given 25 blows from the rammer dropped from a height of 18 in (45·8 cm) above the soil. The blows shall be uniformly distributed over the surface of each layer. The operator shall ensure that the tube of the rammer is kept clear of soil so that the rammer always falls freely.

The amount of soil used shall be sufficient to fill the mould, leaving not more than about ¼ in (6 mm) to be struck off when the extension is removed (see Note 5). The extension shall be removed and the compacted soil shall be carefully levelled off to the top of the mould by means of the straightedge. The mould and soil shall then be weighed to the nearest 1 g (W_2).

(3) The compacted soil specimen shall be removed from the mould and placed on the large metal tray. A representative sample of the specimen shall be taken and its moisture content (m) shall be determined as in Test 1(A), 1(B) or 1(C).

(4) The remainder of the soil specimen shall be broken up, rubbed through the ¾ in (20 mm) BS test sieve*, and then mixed with the remainder of the original sample. Suitable increments of water (see Note 6) shall be successively added and mixed into the sample, and the above procedure from operations (2) to (4) shall be repeated for each increment of water added. The total number of determinations made shall be at least five, and the range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

4.2.3.2 ***Soil susceptible to crushing during compaction*** (see Note 1)

(1) Five or more 2½ kg samples of air-dried soil passing the ¾ in (20 mm) BS test sieve, obtained as described in 1.4, shall be taken (see Note 2). The samples shall each be thoroughly mixed with different amounts of water to give a suitable range of moisture contents (see Notes 3 and 4). The range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range (see Note 6).

(2) Each sample shall be treated as in 4.2.3.1 (2).

(3) Each compacted specimen shall be treated as in 4.2.3.1 (3).

(4) The remainder of each soil specimen shall be discarded.

* BS 410, 'Test sieves'.

4.2.4 Calculations*

(1) The weight of wet compacted soil per cubic foot (bulk density, γ) of each compacted specimen shall be calculated from the formula (see Note 7):

$$\gamma = \frac{W_2 - W_1}{15 \cdot 12} \text{ (lb/ft}^3\text{)}$$

where W_1 = weight of mould and base (g)
W_2 = weight of mould, base and soil (g).

(2) The weight of dry soil per cubic foot (dry density, γ_d) shall be calculated from the formula:

$$\gamma_d = \frac{100\gamma}{100 + m} \text{ (lb/ft}^3\text{)}$$

where m = moisture content of soil (per cent).

(3) The dry densities (γ_d) obtained in a series of determination shall be plotted against the corresponding moisture contents (m). A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve shall be determined; the zero, 5% and 10% air voids lines shall be plotted for comparison (see 1.1).

4.2.5 Reporting of results

4.2.5.1 The following values shall be reported:

(1) The dry density in lb/ft³ corresponding to the maximum point on the moisture content/dry density curve shall be reported as the 'maximum dry density', to the nearest whole number.

(2) The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the 'optimum moisture content' and quoted to the nearest 0·2 for values below 5%, to the nearest 0·5 for values from 5% to 10%, and to the nearest whole number for values exceeding 10% (see Note 8).

(3) The amount of stone retained on the ¾ in (20 mm) BS test sieve† shall be reported to the nearest 1%.

4.2.5.2 The method of obtaining the result shall be stated, i.e. BS 10 lb (4·5 kg) rammer method. The procedure used shall also be stated, i.e. single sample *or* separate samples.

* See Form M, Appendix B.
† BS 410, 'Test sieves'.

NOTES ON TEST 12

NOTE 1. The soil should be considered susceptible to crushing during compaction if the sample contains granular material of a soft nature, e.g. soft limestone, sandstone, etc., which is reduced in size by the action of the 10 lb (4·5 kg) rammer. The procedure given in 4.2.3.2 for soils susceptible to crushing during compaction can be applied to all soils if it is convenient to do so.

NOTE 2. The removal of small amounts of stone (up to 5%) retained on a ¾ in (20 mm) BS test sieve* will affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density. The exclusion of a large proportion of stone coarser than ¾ in (20 mm) (such as is present for example in a gravel of 3 in (76 mm) maximum size) may have a major effect on the density obtained compared with that obtainable with the soil as a whole, and on the optimum moisture content. There is at present no generally accepted method of testing or of calculation for dealing with this difficulty in comparing laboratory compaction test results with densities obtained in the field. The following notes may be of assistance in providing a basis for action which will avoid major errors; they are not considered comprehensive, however, and are not to be read as part of the standard method of test. (The term gravel should be taken to include rock fragments.)

(1) For soils containing up to about 20% or 25% of coarse gravel or cobbles, a correction may be calculated for the maximum dry density based on the displacement of a proportion of soil of given density by stone of known specific gravity. A check of the validity of this calculation may be obtained by replacing the coarse gravel in the soil by an equal amount of ¾–⅜ in (20–10 mm) gravel of similar characteristics and carrying out a compaction test on this material. For soils containing little fine or medium gravel the proportion of coarse gravel permissible may be extended to 40% or 50%.

(2) For soils containing larger proportions of coarse gravel or cobbles, various methods have been advocated, but it is not considered that any can be satisfactory which does not involve the use of a mould which is large compared with the maximum size of gravel or cobbles involved. It is common to carry out the compaction tests on such soils in a 6 in (15 cm) diameter mould of the same depth (4·584 in) (11·6 cm) as the standard mould. When this is done the number of blows per layer should be increased from 25 to 56 to allow for the increased area. California Bearing Ratio (CBR) moulds are sometimes used for this purpose but because of the difference in height (5 in) (13 cm) the number of blows per layer should be increased to 61.

NOTE 3. The amount of water to be mixed with air-dried soil at the commencement of the test will vary with the type of soil under test. In general, with sandy and gravelly soils a moisture content of 3% to 5% would be suitable, while with cohesive soils a moisture content about 12% to 16% below the plastic limit of the soil (PL-16 to PL-12) would usually be suitable.

NOTE 4. It is important that the water shall be thoroughly and adequately mixed with the soil, since inadequate mixing gives rise to variable test results. This is particularly important with cohesive soils when adding a substantial quantity of water to the air-dried soil. With clays of high plasticity, or where hand mixing is employed, it may be difficult to distribute the water uniformly through the air-dried soil by mixing alone, and it may be necessary to store the mixed sample in a sealed container for a minimum period of about 16 hours before continuing with the test.

NOTE 5. It is necessary to control the total volume of soil compacted, since it has been found that if the amount of soil struck off, after removing the extension, is too great, the test results will be inaccurate.

* BS 410, 'Test sieves'.

NOTE 6. The water added for each stage of the test should be such that a range of moisture contents is obtained which includes the optimum moisture content. In general, increments of 1–2 % are suitable for sandy and gravelly soils and of 2–4 % for cohesive soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum moisture content.

NOTE 7. The constant 15·12 only applies when the dimensions of the mould are as given in 4.2.2(1).

NOTE 8. For some highly permeable soils such as clean gravels, uniformly graded and coarse clean sands the results of the laboratory compaction test (10 lb (4·5 kg) rammer method), may provide only a poor guide for specifications on field compaction. The laboratory test often indicates higher values of optimum moisture content than would be desirable for field compaction and the maximum dry density is often much lower than the state of compaction that can readily be obtained in the field.

4.3 TEST 13. DETERMINATION OF THE DRY DENSITY/MOISTURE CONTENT RELATION OF GRANULAR SOIL-VIBRATING HAMMER METHOD

4.3.1 Scope. This method covers the determination of the weights of dry soil per cubic foot when the soil is compacted in a specified manner over a range of moisture contents, including that giving the maximum weight of dry soil per cubic foot. In this test, which is suitable for fine-grained granular soils and for the fraction of medium- and coarse-grained granular soils passing the 1½ in (40 mm) BS test sieve*, the soil is compacted into a California Bearing Ratio mould of 6 in (15 cm) diameter and 5 in (13 cm) depth, using an electrically operated vibrating hammer (see Note 1).

4.3.2 Apparatus

(1) A cylindrical metal mould having an internal diameter of 6 in (15·2 cm) and an internal effective height of 5 in (12·7 cm), with a detachable base plate and a collar 2 in (5·1 cm) deep, as described in Test 15 (determination of the California Bearing Ratio) in this standard. A thin coating of oil shall be applied to the internal faces of the mould and collar before each test.

(2) An electric vibrating hammer having a power consumption between 600 and 750 watts and operating at a frequency between 1500 and 2500 cycles per minute (see Note 2).

(3) A steel tamper attached to the vibrating hammer; the tamper shall have a circular foot of 5¾ in (14·6 cm) diameter and shall not exceed 7 lb (3·18 kg) in weight. One suitable design of tamper is shown in Fig. 24.

(4) A balance readable and accurate to 5 g.

(5) A 1½ in (40 mm) BS test sieve and receiver.

(6) A straightedge, e.g. a steel strip 12 in (30 cm) long, 1 in (2·5 cm) wide and ⅛ in (3 mm) thick.

(7) A device which will enable the sample depth to be measured to an accuracy of 1/50 in (0·5 mm), e.g. a depth gauge or steel rule.

(8) A large metal tray (a convenient size is one about 24 in (60 cm) × 18 in (45 cm) and with sides 3 in (7 cm) deep).

(9) A stop-watch or stop-clock.

(10) Apparatus for the determination of moisture content in accordance with Test 1(A), 1(B) or 1(C) of this standard.

(11) Apparatus for extracting specimens from the mould (optional).

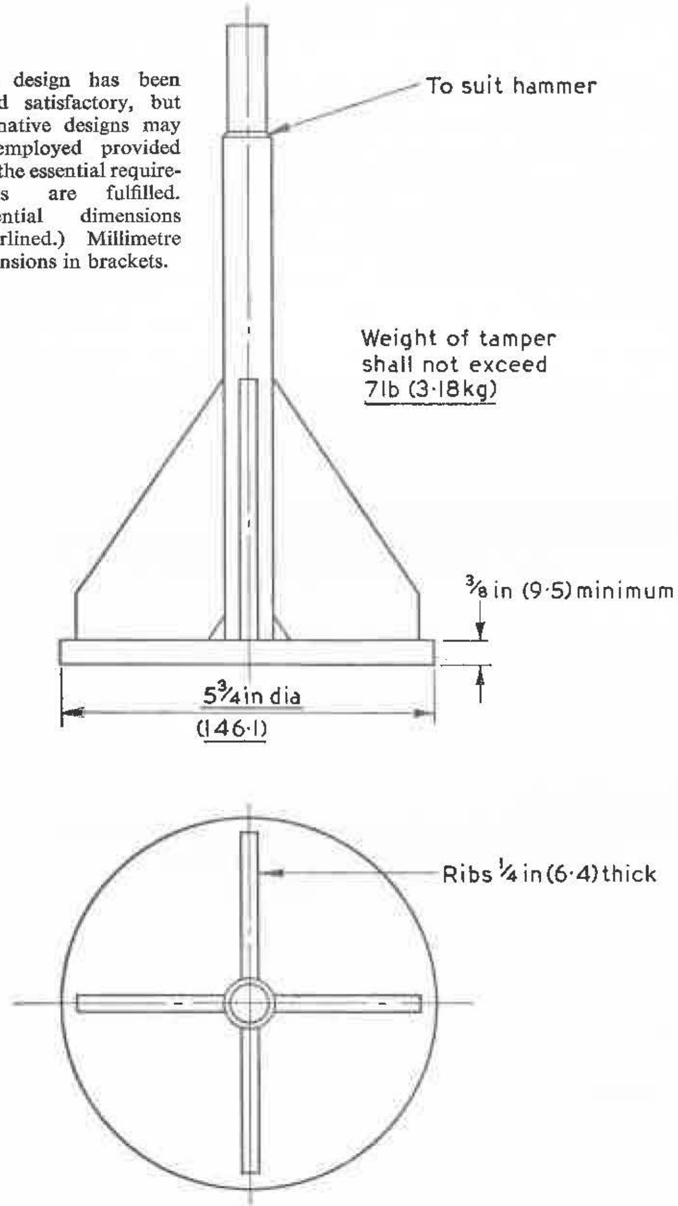
4.3.3 Procedure

4.3.3.1 ***Soil not susceptible to crushing during compaction*** (see Note 3)

(1) A 25 kg sample of air-dried soil passing the 1½ in (40 mm) BS test sieve, obtained as described in 1.4, shall be taken. The sample shall be mixed thoroughly with a suitable amount of water depending on the soil type (see Notes 4 and 5).

* BS 410, 'Test sieves'.

This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions underlined.) Millimetre dimensions in brackets.



All welded construction.
Material: steel.

Fig. 24. Tamper for the vibrating hammer compaction test

(2) The mould, together with its two-inch collar and base-plate firmly fixed, shall be weighed (W_1), and then stood on a solid base, e.g. a concrete floor or plinth. A quantity of the moist soil, sufficient to give a specimen 5 to 5¼ in (12·7 to 13·3 cm) deep after compaction in the mould, shall be compacted in the mould in three layers of approximately equal weight, using the vibrating hammer fitted with the circular steel tamper. Each layer shall be compacted for a period of 60 seconds and throughout this period a firm downward pressure shall be applied to the vibrating hammer so that the total downward load, including the weight of the hammer and tamper, shall be between 70 and 90 lb (32 and 41 kg) (see Note 6).

(3) When the final layer has been compacted, any loose material around the sides of the mould shall be removed from the surface of the specimen. The straightedge shall be laid across the top of the collar of the mould and the depth of the specimen below the top of the collar measured to an accuracy of 1/50 in. Readings shall be taken at four points spread evenly over the surface of the specimen, all at least ½ in (1·3 cm) from the side of the mould, and the mean height (h) of the specimen calculated. If the specimen is more than 5¼ in (13·3 cm) or less than 5 in (12·7 cm) in height, it shall be rejected and a further test carried out.

(4) The mould, together with the collar, base-plate and soil shall be weighed to the nearest 5 g (W_2).

(5) The compacted soil specimen shall be removed from the mould and placed on the large metal tray. A representative sample of the specimen shall be taken and its moisture content (m) shall be determined as in Test 1(A), 1(B) or 1(C).

(6) The remainder of the soil specimen shall be broken up and then mixed with the remainder of the original sample. Suitable increments of water (see Note 7) shall be successively added and mixed into the sample, and the above procedure from operations (2) to (6) shall be repeated for each increment of water added. The total number of determinations made shall be at least five, and the range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

4.3.3.2 ***Soil susceptible to crushing during compaction*** (see Note 3)

(1) Five or more 8 kg samples of air-dried soil passing the 1½ in (40 mm) BS test sieve*, obtained as described in 1.4 shall be taken. The samples shall each be thoroughly mixed with different amounts of water to give a suitable range of moisture contents (see Notes 4 and 5). The range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range (see Note 7).

(2) Each sample shall be treated as in 4.3.3.1 (2).

(3) As 4.3.3.1 (3).

* BS 410, 'Test sieves'.

(4) As 4.3.3.1(4).

(5) Each compacted specimen shall be treated as in 4.3.3.1(5).

(6) The remainder of each soil specimen shall be discarded.

4.3.4 Calculations*

(1) The weight of soil in lb/ft³ (bulk density, γ) of each compacted density specimen shall be calculated from the formula:

$$\gamma = \frac{W_2 - W_1}{7{\cdot}42h} \text{ (lb/ft}^3\text{) (see Note 8)}$$

where W_1 = weight of the mould + base + collar (g)
W_2 = weight of the mould + base + collar + compacted specimen (g)
h = height of specimen (in).

(2) The weight of dry soil in lb/ft³ (dry density, γ_d), shall be calculated from the formula:

$$\gamma_d = \frac{100\gamma}{100 + m} \text{ (lb/ft}^3\text{)}$$

where m = moisture content of the soil (per cent).

(3) The dry densities (γ_d), obtained in a series of determinations, shall be plotted against the corresponding moisture contents (m). A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve determined, and the zero, 5% and 10% air voids lines plotted for comparison (see 1.1).

4.3.5 Reporting of results

4.3.5.1 The following values shall be reported:

(1) The dry density in lb/ft³ corresponding to the maximum point on the moisture content/dry density curve shall be reported as the 'maximum dry density' to the nearest whole number.

(2) The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the 'optimum moisture content' and quoted to the nearest 0·2 for values below 5%, to the nearest 0·5 for values from 5% to 10%, and to the nearest whole number for values exceeding 10%.

(3) The amount of stone retained on the 1½ in (40 mm) BS test sieve shall be reported to the nearest 1%.

4.3.5.2 The method of obtaining the result shall be stated, i.e. BS vibrating hammer method. The procedure used shall also be stated, i.e. single sample or separate samples.

* See Form N, Appendix B.

NOTES ON TEST 13

NOTE 1. The vibrating hammer method may be used on granular soils and is preferred to Tests 11 and 12 in the case of highly permeable soils, such as clean gravels, uniformly graded and coarse clean sands, on which Tests 11 and 12 may provide only a poor guide for specifications on site compaction. Results given by the vibrating hammer method provide a satisfactory guide to the optimum moisture content for site compaction, and, generally, the maximum density given by the test is only slightly greater than that obtainable on the site.

NOTE 2. It is important that the hammer used shall have been maintained properly in accordance with the manufacturer's instructions and that its working parts are not badly worn.

To determine that a vibrating hammer complying with the requirements of this test is in satisfactory working order the following test may be carried out:

A 10 kg sample shall be taken of Leighton Buzzard silica sand, at least 75% of which shall pass the No. 25 (600 microns) BS test sieve* and be retained on the No. 36 (420 microns) BS test sieve and all of which shall pass the No. 18 (850 microns) BS test sieve and be retained on the No. 52 (300 microns) BS test sieve. It shall be dry and shall not have been previously used. This sand shall be sieved through a No. 25 (600 microns) BS test sieve and the coarse fraction discarded. Water shall be mixed with the sand finer than the No. 25 (600 microns) BS test sieve sufficient to raise its moisture content to 2·5% ± 0·5%.

The wet sand shall be compacted in the cylindrical metal mould, 6 in (15 cm) diameter and 5 in (13 cm) deep, using the vibrating hammer under consideration, exactly according to the procedure given in 4.3.3.1(2) to (5). A total of three tests shall be carried out, all on the same sample of sand, and the mean dry density determined. The dry density values shall be determined to the nearest 0·1 lb/ft³, and if the range of values in the three tests exceeds 0·5 lb/ft³ the procedure shall be repeated. The vibrating hammer shall be considered suitable for use in the vibrating compaction test if the mean dry density of the sand exceeds 108·5 lb/ft³.

NOTE 3. The soil should be considered susceptible to crushing during compaction if the sample contains granular material of a soft nature, e.g. soft limestone, sandstone, etc., which is reduced in size by the action of the vibrating hammer. The procedure given in 4.3.3.2 for soils susceptible to crushing during compaction can be applied to all granular soils if it is convenient to do so.

NOTE 4. The amount of water to be mixed with air-dried soil at the commencement of the test will vary with the type of soil under test. In general, with sandy and gravelly soils a moisture content of 3% to 5% would be suitable.

NOTE 5. It is important that the water shall be thoroughly and adequately mixed with the soil, since inadequate mixing gives rise to variable test results.

NOTE 6. The application of pressure combined with vibration is essential to ensure the required degree of compaction. The downward load required of 70–90 lb (32–41 kg), including the weight of the hammer and tamper, is greater than that required to prevent the hammer bouncing on the soil. It has been found, in practice, that operators can usually judge, with sufficient accuracy, the required pressure, but it is recommended that, when an operator lacks experience in this test, the vibrating hammer should initially be applied, without vibration, to a platform scale to determine the pressure to be applied.

NOTE 7. The water added for each stage of the test should be such that a range of moisture contents is obtained which includes the optimum moisture content. In general, increments of 1–2% are suitable for sandy and gravelly soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum moisture content.

NOTE 8. The constant 7·42 only applies when the diameter of the mould is correct, i.e. 6 in (15·2 cm).

* BS 410, 'Test sieves'.

4.4 TEST 14. DETERMINATION OF THE DRY DENSITY OF SOIL ON THE SITE

4.4.1 Test 14(A). Sand replacement method suitable for fine- and medium-grained soils—Small pouring cylinder method

4.4.1.1 ***Scope.*** This method covers the determination in situ of the dry density (weight of dry soil per cubic foot) of compacted fine- and medium-grained soils for which a 4½ in (11 cm) diameter sand-pouring cylinder is used. The method is applicable to layers not exceeding 6 in (15 cm) in thickness (see Note 1).

4.4.1.2 ***Apparatus***

(1) A pouring cylinder similar in the essential details to that shown in Fig. 25.

(2) Suitable tools for excavating holes in soil, e.g. bent spoon, dibber as shown in Fig. 26, a scraper tool similar to that shown in Fig. 27 to make a level surface.

(3) A cylindrical metal calibrating container with an internal diameter of 4 in (10 cm) and an internal depth of 6 in (15 cm) (see Note 2) of the type illustrated in Fig. 28 fitted with a lip 2 in (5 cm) wide and about 3/16 in (4·5 mm) thick surrounding the open end.

(4) A balance readable and accurate to 1 g.

(5) A glass plate about 18 in (45 cm) square and ⅜ in (9 mm) thick or larger.

(6) Metal tray or container to take excavated soil (a convenient size is one about 12 in (30 cm) diameter and 1½ in (4 cm) deep).

(7) A cylindrical steel core-cutter, 5 in (12·7 cm) long and 4 in (10 cm) internal diameter, with a wall thickness of ⅛ in (3 mm) bevelled at one end. One suitable type is illustrated in Fig. 31. This cutter shall be kept adequately greased.

(8) Apparatus for moisture content determination as described in Test 1(A), 1(B) or 1(C).

(9) A metal tray 12 in (30 cm) square and 1½ in (4 cm) deep with a 4 in (10 cm) diameter hole in the centre.

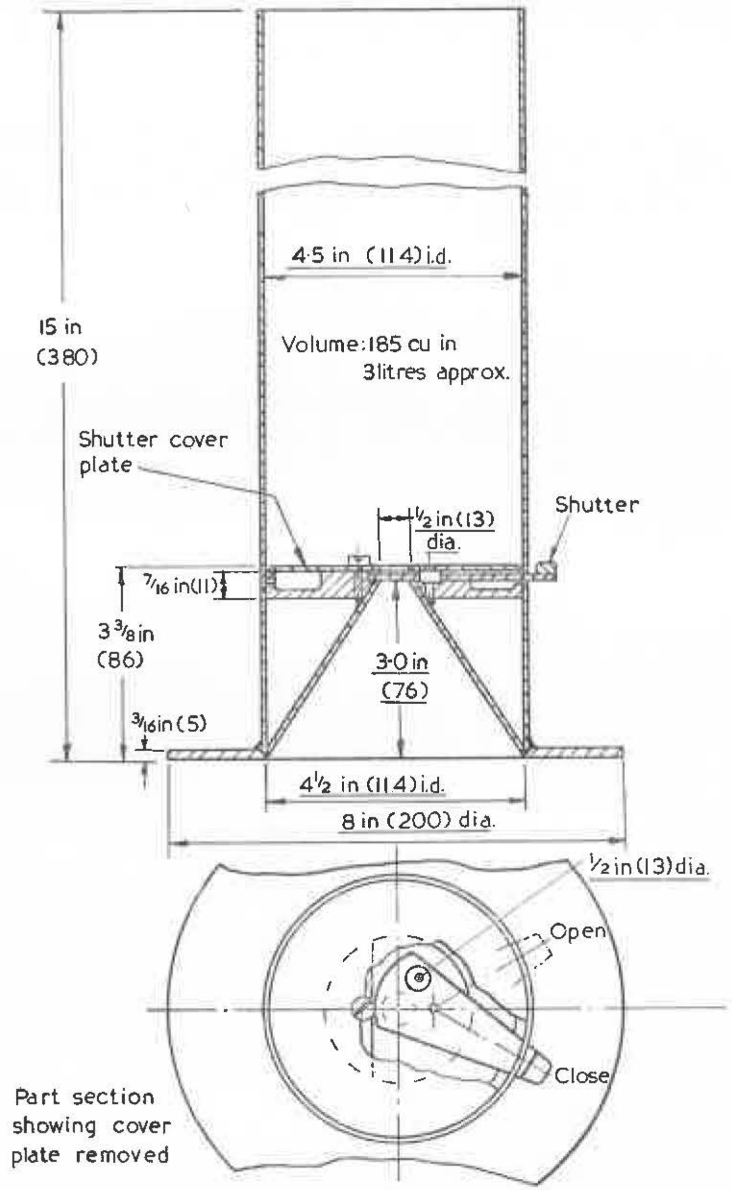
4.4.1.3 ***Material.*** Clean, closely-grained natural sand, e.g. material passing the No. 25 (600 microns) and retained on the No. 52 (300 microns) BS test sieve* and free from organic matter, which has been oven-dried and stored for a suitable period to allow its moisture content to reach equilibrium with atmospheric humidity (see Note 3).

4.4.1.4 ***Calibration of apparatus***

4.4.1.4.1 *Determination of the weight of sand in the cone of the pouring cylinder*

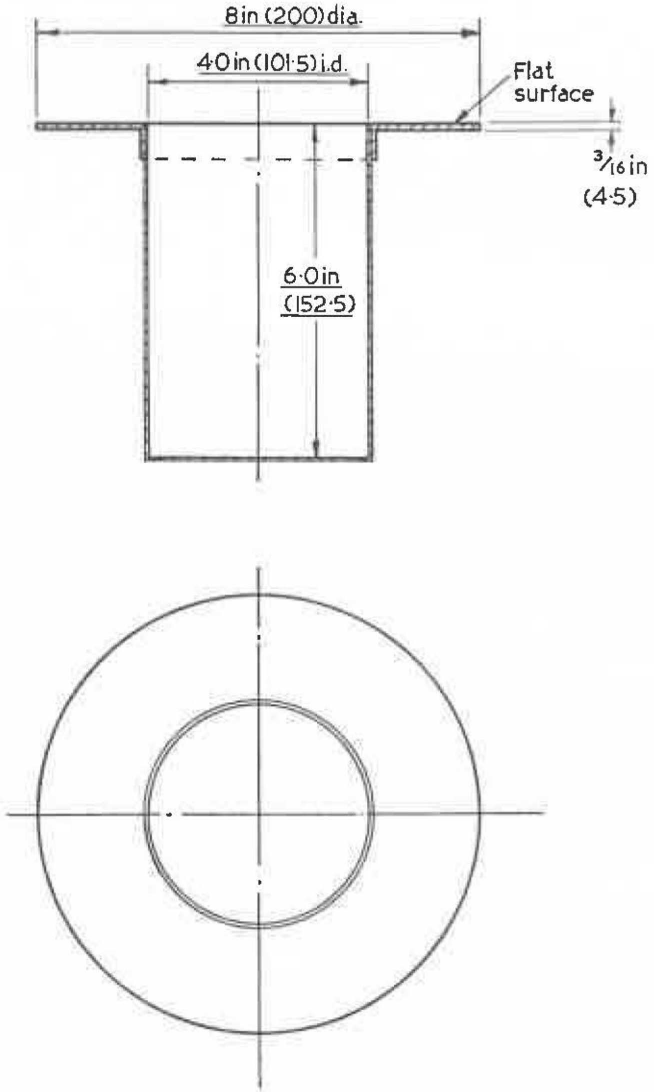
(1) The pouring cylinder shall be filled so that the level of the sand in the cylinder is within about ½ in (13 mm) of the top. Its total initial weight (W_1)

* BS 410, 'Test sieves'.



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions underlined.) Millimetre dimensions in brackets.

Fig. 25. Small pouring cylinder for the determination of the dry density of fine- and medium-grained soils



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions underlined.) Millimetre dimensions in brackets.

Fig. 28. Calibrating container for use with the small pouring cylinder

shall be found and shall be maintained constant throughout the tests for which the calibration is used. A volume of sand equivalent to that of the excavated hole in the soil (or equal to that of the calibrating container) shall be allowed to run out. The shutter on the pouring cylinder shall then be closed and the cylinder placed on a plane surface, e.g. the glass plate.

(2) The shutter on the pouring cylinder shall be opened and sand allowed to run out. The pouring cylinder shall not be tapped or otherwise vibrated during this period. When no further movement of sand takes place in the cylinder the shutter shall be closed and the cylinder removed carefully.

(3) The sand that has filled the cone of the pouring cylinder shall be collected and weighed to the nearest gramme.

(4) These measurements shall be repeated at least three times and the mean weight (W_2) taken.

4.4.1.4.2 *Determination of the bulk density of the sand* (γ_s)

(1) The internal volume (V) in ml of the calibrating container shall be determined from the weight of water required to fill it (see Notes 2 and 4).

(2) The pouring cylinder shall be placed concentrically on the top of the calibrating can after being filled to the constant weight (W_1) as in 4.4.1.4.1 (1). The shutter on the pouring cylinder shall be closed during this operation. The shutter shall be opened and sand allowed to run out. The pouring cylinder shall not be tapped or otherwise vibrated during this period. When no further movement of sand takes place in the cylinder the shutter shall be closed. The pouring cylinder shall be removed and weighed to the nearest gramme.

(3) These measurements shall be repeated at least three times and the mean weight (W_3) taken (see Note 5).

4.4.1.5 ***Measurement of soil density***

4.4.1.5.1 A flat area, approximately 1 ft 6 in (45 cm) square, of the soil to be tested shall be exposed and trimmed down to a level surface, preferably with the aid of the scraper tool.

4.4.1.5.2

(1) A round hole approximately 4 in (10 cm) diameter and the depth of the layer to be tested up to a maximum of 6 in (15 cm) deep (see Note 2) shall be excavated in the soil (see Note 6). No loose material shall be left in the hole. The metal tray shall be laid on the prepared surface of the soil with the hole over the portion of the soil to be tested; the hole in the soil shall then be excavated using the hole in the tray as a pattern. This tray shall be removed before the pouring cylinder is placed in position over the excavated hole. The excavated soil shall be carefully collected and weighed to the nearest gramme (W_w).

(2) The following alternative method shall be used for fine-grained cohesionless soils:

The steel core cutter (see Fig. 31) shall be pressed evenly and carefully into the soil until its top edge is flush with the levelled surface. Soil to a depth of about 4½ in (11 cm) (see Note 2) within the core cutter shall then be excavated by means of suitable tools. The excavated soil shall be carefully collected and weighed to the nearest gramme (W_w). The core cutter shall remain in position during the remainder of the testing procedure.

4.4.1.5.3 A representative sample of the excavated soil shall be placed in an airtight container and its moisture content (m) shall be determined as in Test 1(A), 1(B) or 1(C). Alternatively the whole of the excavated soil may be dried and weighed (W_d).

4.4.1.5.4 The pouring cylinder filled to the constant weight (W_1) as in 4.4.1.4.1 (1) shall be placed so that the base of the cylinder covers the hole concentrically. The shutter on the pouring cylinder shall be closed during this operation. The shutter shall then be opened and sand allowed to run out. The pouring cylinder and the surrounding area shall not be vibrated during this period. When no further movement of the sand takes place the shutter shall be closed. The cylinder shall be removed and weighed to the nearest gramme (W_4) (see Note 7).

4.4.1.6 ***Calculations****

(1) The weight of sand (g) required to fill the calibrating container (W_a) shall be calculated from the formula:

$$W_a = W_1 - W_3 - W_2$$

where W_1 = weight of cylinder and sand before pouring into calibrating can (g)
W_3 = mean weight of cylinder and sand after pouring into calibrating can (g)
W_2 = mean weight of sand in cone (g).

(2) The bulk density of the sand (γ_s) in lb/ft³ shall be calculated from the formula:

$$\gamma_s = \frac{W_a}{V} \times 62{\cdot}4$$

where V = volume of calibrating can in ml.

(3) The weight of sand (g) required to fill the excavated hole (W_b) shall be calculated from the formula:

$$W_b = W_1 - W_4 - W_2$$

* See Form O, Appendix B.

where W_1 = weight of cylinder and sand before pouring into hole (g)
W_4 = weight of cylinder and sand after pouring into hole (g)
W_2 = mean weight of sand in cone (g).

(4) The weight of wet soil per cubic foot (bulk density (γ)) shall be calculated from the formula:

$$\gamma = \frac{W_w}{W_b} \times \gamma_s \text{ (lb/ft}^3\text{)}$$

where W_w = weight of soil excavated (g)
W_b = weight of sand required to fill the hole (g)
γ_s = bulk density of sand (lb/ft³).

(5) The weight of dry soil per cubic foot (dry density, γ_d) shall be calculated from the formulae:

$$\gamma_d = \frac{100\gamma}{100 + m} \text{ (lb/ft}^3\text{)}$$

where m = moisture content of the soil (per cent)

or

$$\gamma_d = \frac{W_d}{W_b} \times \gamma_s \text{ (lb/ft}^3\text{)}$$

where W_d = weight of dry soil from the hole (g)
W_b = weight of sand required to fill the hole (g).

4.4.1.7 ***Reporting of results.*** The following values shall be reported:

(1) Dry density of soil (lb/ft³) to the nearest whole number.
(2) Moisture content of the soil (per cent) quoted to two significant figures.

The method of obtaining the results shall also be stated, i.e. BS small pouring cylinder method.

NOTES ON TEST 14(A)

NOTE 1. With granular materials having little or no cohesion particularly when they are wet, there is a danger of errors in the measurement of dry density by this method. These errors are caused by the 'slumping' of the sides of the excavated density hole and always result in an over-estimation of the density.

NOTE 2. Depth of hole excavated. If for any reason it is necessary to excavate the holes to depths other than 6 in (15 cm), the calibrating container should be replaced by one the depth of which is the same as the hole excavated or its effective depth should be reduced to that of the hole excavated.

NOTE 3. Generally a storage period, after oven drying, of about 7 days is sufficient for the moisture content of the sand to reach equilibrium with the atmospheric humidity. The sand should not be stored in airtight containers and should be thoroughly mixed before use. If sand is salvaged from holes in compacted soils after carrying out this test, it is advisable to sieve, dry and store this sand again before it is used in further sand-replacement tests.